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Development of an Eye Camera for Use with Motion Pictures

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FOREWORD

ALTHOUGH there has been considerable research on the over-all effectiveness of educational motion pictures, very little is known about their psychological impact on individuals. We know very little about how we communicate meanings by motion pictures. The design of film scenes and sequences is left largely to the intuition of producers. Investigations of perception have covered some of the basic considerations in how meaning is conveyed by visual teaching materials but many experiments are necessary before we get sufficient clues as to how best to construct these materials. New techniques and new apparatus need to be developed for this research.

This monograph describes one approach to this problem. The eye camera used previously in research in eye movements in reading was adapted for use with motion pictures. The camera is synchronized with the educational motion picture being viewed so that fixations can be determined for each frame of the teaching film. The eye-camera film moves intermittently, making a framed motion-picture record. This can be superimposed directly on the educational motion picture viewed by the subject. Eye dots can be located directly on the motion-picture screen indicating exactly each eye fixation. Corrections are easily made for slight head movements. Thus we can quickly determine what a student looks at when viewing a motion picture.

This equipment and improvements on it may make it possible for us to make analyses of how we learn from motion pictures and how they could be better designed to teach more effectively.

WALTER W. COOK

University of Minnesota
December 1, 1950

TABLE OF CONTENTS

DEVELOPMENT OF AN EYE CAMERA FOR USE WITH MOTION PICTURES*

I. INTRODUCTION

Motion pictures have come into wide use in the field of teaching and are destined for much more use. But experimentation has, so far, merely indicated that they are effective, not why they are effective nor how this effectiveness is achieved. Furthermore, research has been concerned entirely with the over-all effectiveness of an entire film, not with the effectiveness of scenes or sequences within the film. Yet the teaching value of an entire film is based on the teaching value of its parts. Within any one motion-picture scene, it is still impossible to tell which elements are effective in teaching and which are not.

The determination of the effectiveness of parts of films will be of interest primarily to educators who wish to exert more control over the translation of their ideas into motion-picture scenes. No one can tell, furthermore, whether the money and effort put into any one scene by the producer is justified by the actual learning accomplished in a classroom where the film is used. If such information were available, large savings might be possible.

Methods need to be devised to determine which elements contribute to the teaching value of the film and which do not. One line of attack is to adapt the eye camera used in measuring eye movements in reading to measuring eye movements while pupils are looking at educational motion pictures. This paper describes this method.

II. CRITERIA FOR A METHOD OF MEASURING EYE MOVEMENTS OF SUBJECTS VIEWING MOTION PICTURES

The eye camera had to satisfy the following criteria:

1. It must provide a record of both vertical and horizontal eye movements on one film.

2. It must move the film intermittently as in a motion-picture projector, so that the resulting record can be projected directly for analysis.

3. It must operate as nearly as possible at the projection speed of educational motion pictures (24 frames per second).

4. It must provide maximum comfort for the subject so that the situation of viewing the teaching film will be as nearly natural as possible.

A. Types of Eye-Movement Measures

Obtaining eye-movement measures of subjects looking at motion pictures differs in several important ways from obtaining eye-movement measures during the process of reading.

Not all the measures of eye movements which are useful in reading seem to be applicable to

* The apparatus herein described was developed as part of a study conducted under the generous guidance of Dr. Walter W. Cook. Dr. Miles A. Tinker contributed from his extensive experience in analyzing eye movements. The original eye camera that is here adapted for motion pictures was developed by Dr. Herman R. Brandt. Mr. Peyton Stallings, Miss Dolores Paul, and Mrs. Evon Unruh contributed invaluable assistance.

the viewing of motion pictures. The measures of eye movements are: (*a*) pause duration, (*b*) span, (*c*) fixation frequency, and (*d*) regression frequency. Tinker (6) has stated that of these, the two most closely associated with reading ability are fixation frequency and regression frequency, and that pause duration is one of the worst measures of reading ability because it varies so much with the type of reading material.

Regression frequency cannot apply to pictures, either still or motion, because pictures are not read from left to right or in any standard direction as in reading, even though Brandt (1, p. 57) has found a slight tendency for the eyes to make more fixations in the upper left quadrant in viewing symmetrical designs.

Fixation frequency would probably not be a very good measure of eye movements with motion pictures because of the constant speed factor in motion pictures. Sound films move at a speed of 24 individual frames per second, and the average motion-picture scene lasts only 6 seconds. In a good teaching film, individual scenes follow each other in very rapid succession, putting pressure on the viewer to assimilate as much detail as possible in the time allowed, which is always too little to give the viewer time to see everything. In this situation, fixation frequency would probably be negatively correlated to a high degree with pause duration. Its value might be close to a mere inverse of the value of pause duration and merely duplicate the investigation of pause duration. Thus, fixation frequency theoretically seemed to have little possibility as a good measure of eye movements in this experiment, although it might prove to have some value after the first few pioneering experiments have been made to explore the field.

The two measures that remain, span and pause duration, seemed to be the best to use in this experiment. Although pause duration, as mentioned above, has turned out to be one of the worst measures of reading ability, it seemed on a theoretical basis that it might be much more useful as a measure of eye movements in scanning motion pictures. The term "span" in reading research commonly refers to the amount of one line of type which is comprehended by the reader in one fixation by the use of peripheral as well as foveal vision. Such a concept in viewing pictures would not be useful in these early stages of research on pictures. A comparable measure, however, would be *the linear distance in any direction traveled by the eye between any two consecutive fixations.* It was decided to call this distance the *interfixation movement,* to distinguish it clearly from span.

Mention should be made here of the term "return sweep" which is used in reading research. It refers to the movement of the eye in moving from one end of a line of type which has been read to the first fixation on the next line of type. Because the term return sweep has such a specialized meaning connected with the lines of type, it was decided not to apply it to viewing pictures.

The method of recording eye movements, therefore, should be capable of giving fairly exact measures of *interfixation movement* and *pause duration.*

B. Need of Locating Fixations in Two-Dimensional Plane

The measuring method needed also to tell *where the eye is fixated* in a two-dimensional plane perpendicular to the line of vision. In reading research, it is usually sufficient to measure the lateral movement of the eyes from left to right. In viewing pictures, it is necessary to locate these fixations on a two-dimensional plane by measuring not only the lateral movements, but also the vertical movements, simultaneously.

C. Eye-Camera Speed As Near As Possible to Twenty-Four Frames Per Second

If an eye camera were used for measuring the viewing of motion pictures, it would be especially useful if the film advanced through the eye camera at 24 frames per second, the same speed that the motion picture is projected on the screen. If at this speed each fixation were

represented by one dot in two dimensions in a frame of the film, then the eye-camera film would have a one to one relationship to the teaching film being viewed. It would be possible, in this ideal situation, to project the eye-camera film on the screen, thus superimposing the actual fixation dot on the motion-picture scene which caused this fixation.

It seemed at the beginning that it might even be possible, ideally, to project the eye-camera record in some instances by a motion-picture projector, superimposed on the screen on the teaching film image which, of course, would also be run in synchronism in a motion-picture projector. The effect on the screen would be that of a moving fixation dot, moving about on the screen exactly in the same way in which the subject viewed the teaching film. If such a method could be developed, it would even be possible to synchronize several projectors and contrast or compare the fixations of several subjects selected as typical or atypical from a particular point of view. In practice it was found that this ideal of making eye records at 24 frames per second and projecting them in a motion-picture projector could not be realized owing to the limitations of cameras now available. A compromise speed had to be accepted, and the motion-picture projection of eye records deferred to a later experiment.

D. Comfort of the Viewer

Another very desirable criterion of a machine for measuring eye movements with motion pictures was the comfort of the viewer. The basic reason for this was that printed words are symbols, whereas motion pictures are close to reality. Reading is, therefore, expected to be done in a somewhat constrained physical position, whereas the viewing of motion pictures allows considerable freedom of movement.

It was also necessary to make the eye-movement records in a room with subdued light, since the subjects would be viewing motion pictures. To view motion pictures in a room even partially illuminated would ruin any effective realism which the motion picture might be trying to create.

Finally, it was desirable to find a method of making eye-movement records which would not involve shining too bright a light into the subject's eyes, because this would be especially trying when the subject was looking at motion pictures in a darkened room.

III. METHODS OF MAKING EYE RECORDS

The standard corneal-reflection type of eye camera produces a record on 35-mm. film consisting of a series of dots closely spaced. The film is not moved intermittently as in a motion-picture camera but continuously as in a smoked-paper tracing.

Buswell (2) measured eye movements in two dimensions during viewing of pictures by using two recording films at right angles to each other moving synchronously and continuously. Analysis was made by computation.

The camera developed at Purdue University is simply an 8-mm. motion-picture camera taking pictures of the subject's eyes reflected in a half-silvered mirror. Trained analysts can tell at which large area of the material the subject is looking. The method lacks the exactness of the corneal-reflection type of camera but is quick and useful for such tasks as analysis of effectiveness of advertising layouts.

The camera developed by Dr. Herman F. Brandt uses a 35-mm. motion-picture camera moving the film intermittently to photograph the corneal reflection. It pro-

FIGURE 1. The eye camera.

duces a two-dimensional record on framed film. Head movements are also recorded on the film.

This camera came closest to meeting the criteria. It makes a framed motion-picture record which can be analyzed by projection in a filmstrip projector without computation. It has the accuracy of the corneal reflection type. It does not need bright photographic lights.

IV. ADAPTATION OF THE BRANDT CAMERA

A NUMBER of minor changes in the Brandt camera and some major changes in the equipment used with it were made to make it more useful in measuring eye movements of subjects looking at motion pictures.

A. INCREASE IN CAMERA SPEED

The normal speed of the Brandt camera is 2 frames per second. It was the original plan to devise some method of eye photography which would take eye records at 24 frames per second so

that the resulting picture could be projected in a motion-picture camera, superimposed on the screen over the teaching film. It was clear that the Brandt camera mechanism could not be speeded up 12 times. The mechanism would not stand the strain.

It was possible, however, to speed the camera up to some extent. The motor drive of the camera was synchronous, and the motor itself contained a 3 to 1 reduction gear. By removing this gear and attaching the motor drive directly to the secondary gear box, the camera speed was increased from 2 frames per second to 6 frames per second. This was the maximum speed possible with this camera, and it was decided to settle for this, as such a speed would be ample to register most fixations with even the shortest possible duration.

B. Increase in Candle Power of Corneal Light

The corneal light sources were mounted in lamp houses on brackets on either side of the camera. A beam of light aimed at the eye was formed by a fine horizontal slit in the lamp housing. Only the right-hand light was actively used in the experiment since it illuminated both the cornea of the right eye and the surface of the false eye near the right temple. The left-hand corneal light was beamed at the left eye because it was more comfortable for both of the subject's eyes to be illuminated approximately evenly rather than to have one in darkness.

The camera came equipped with a corneal light source of a 1,183 headlight, producing a light intensity of 30 candle power. When the camera was speeded up, it was necessary to obtain more light to expose the photographic film, since the tripling of the camera speed reduced the exposure by one-third. Therefore, the right-hand corneal light was replaced with a 50 candle-power bulb of the same type. The left-hand corneal light source was left at 30 candle power since the imbalance in illumination on the two eyes was not noticeable to the subject.

C. Change of Type of False Eye

As mentioned previously, the camera makes provision for registering on the film the reflection from a false eye. This was a chromium bead attached to a pair of empty spectacle frames. Preliminary tests showed that approximately 10 minutes would be required to fit the spectacle frames to each of the subjects as they varied in physiognomy; therefore, the frames were replaced with a very light earphone head clip to which was attached a chromium cap screw. This cap had greater curvature than the chromium cap on the spectacle frames, and therefore produced a smaller false eye dot on the motion-picture film. It was attached to the earphone head clip by two inches of lead wire which was soft enough to be bent easily. Thus, it was easy to adjust the false eye into the optimum position for each subject. Subjects with broad skulls often required the bending of the false eye toward the right eye so that they would not be too far apart to register on the ground glass of the camera at the same time.

D. Adaptation of Viewing Angle to Motion Pictures

Dr. Brandt's camera was supplied with a mount for copy approximately 2½ feet in front of the subject's eyes and parallel to the plane of the motion-picture film. When the camera was used for this purpose, its natural position al-

lowed the subject to look downward at an angle of approximately 30 degrees to look at the copy.

Even though it would have been possible to project the pictures on the advertising copyholder simply by using a white sheet of paper as a screen and focusing the projector for a very short throw, it was decided not to project the teaching film on a very small screen. When motion pictures are viewed in a reduced size at close range, even though the angle of view for the eyes is exactly the same as it is for a larger screen further away, the realistic effect of the motion picture is lost, probably because the necessity of focusing the eyes at short range makes the subject fully aware that he is not looking at even a close imitation of reality. When motion pictures are projected on a small screen, they give the impression of a peep show. On the other hand, if pictures are projected at a comfortable distance of 10 feet or more away from the subject, he is able to get somewhat of an impression that he is looking at a real scene and project himself into the picture. The Society of Motion Picture Engineers (5) has set up well-established standards for screen size in relation to the viewer in any room used for the screening of motion pictures. The standard states that no seat in the auditorium should be nearer to the screen than twice the width of the screen and no seat should be farther from the screen than five times the width of the screen.

Motion pictures are normally projected so that the subject's line of sight is approximately 10 degrees above the horizontal. To adapt the camera, therefore, for viewing motion pictures, the magazine rack was removed, the camera was elevated about a foot above the height in which it was normally used, and it was tilted down toward the subject. The front half of it was hinged to the table in order to provide stability. Under the back of the camera, a four-inch wooden wedge was placed. By inserting or withdrawing this wedge, the angle of the camera could be adapted to the individual subject. The result was that the reflected beam of light from the cornea entered the lens tube of the camera more horizontally and at about the same angle of reflection as it did formerly.

By extending the sight lines roughly from the subject's eyes past the magazine rack to the wall, the comparable size of the screen was determined. It was reduced somewhat to be safely within the standards of the Society of Motion Picture Engineers. It was not reduced more than absolutely necessary because the camera was designed so that the maximum movement of the subject's eyes in swinging from one side of the copy table to the other was within, and yet filled completely, the area of the eye-camera motion-picture frame. When the size of the screen had been determined, it was checked by actually placing a subject in front of the eye camera and turning on the corneal lights, positioning and focusing the camera, and then asking the subject to sweep his eyes to each of the four corners of the screen in succession while the experimenter checked the movement of the fixation dot on the reflex ground glass of the camera. The movements of the fixation dot were found to be just within the limits of the ground-glass aperture. The final size of the screen was 33″ x 44″ and the distance from the subject to the screen was 8 feet.

In order to keep the subject as much at ease as possible, plenty of foot room

was provided by placing the camera on a small 30″ x 40″ table which provided clearance for the knees. As the subject was to be photographed in a slightly reclining position, the ability to extend his legs forward contributed considerably to his comfort. Since the camera was quite narrow, the subject's arms were placed on the sides of the table on either side of the camera in a relaxed position.

E. Use of an Adjustable Chair

Preliminary tests with the camera showed that, if the subject merely pressed his head against the curved support provided for the forehead and against the brace provided for the chin, the eye records showed excessive head movement. In spite of a desire to give the subject all the comfort possible in order to get as nearly a natural reaction to the motion picture as could be obtained, it was decided that some sort of headrest must be provided. At the same time, it was clear that either the subject's chair or the camera would have to be mounted on a lifting device in order to provide quickly the close vertical adjustments when each student was first seated. (The fine adjustments were made in the camera itself.) The ideal subject chair was found in a standard dentist chair operated by hydraulic lift. This type of chair has so many adjustments on it that it was possible to seat the subjects quickly and exactly in front of the lens tubes of the camera. The arms of the chair had been removed so that it could be slid under the table. Once the subject was seated, the back rest of the chair was brought up to provide a firm support for the subject's back and to make him sit upright so that it was impossible for him to change the level of his eyes by slumping in the chair. Then the hydraulic lift was used to bring the subject's eyes up to the level of the lens tubes so that the narrow beam from the corneal light was exactly centered on the cornea of the right eye. With the hydraulic lift, a very fine adjustment was possible so that the corneal light did not have to be adjusted more than a fraction of an inch.

F. Installation of Bite Stick

In the matter of the headrests, several tests were made. The headrest attached to the camera included both the chin rest and a place to insert a bite stick. Following the principle of using the least constrained position on the subject, some eye records were made with subjects merely resting their chin in the chin rest and pressing their forehead in the forehead rest. It was quickly found that the chin rest forced subjects with long chins to keep their heads higher in the headrest than normal, with the result that the curved band of the forehead rest sometimes came down over their eyebrows, partly obscuring their vision. Subjects with short, round faces found that the forehead rest (which was not adjustable) came too far up on the forehead to provide firm support. Even in small samples of subjects, it was inevitable that different face shapes would be encountered. Therefore, the chin rest was abandoned. The only alternative was to use the bite sticks. These were round, wooden sticks $\frac{1}{8}$ inch in diameter and approximately 6 inches long, obtained from a candy factory. A supply of them was sterilized and kept on hand, a new one being used, of course, for each subject. They were inserted into the machine between two metal supports. Although it seemed unfortunate to introduce such an artificial situation as biting on a stick while viewing motion pictures,

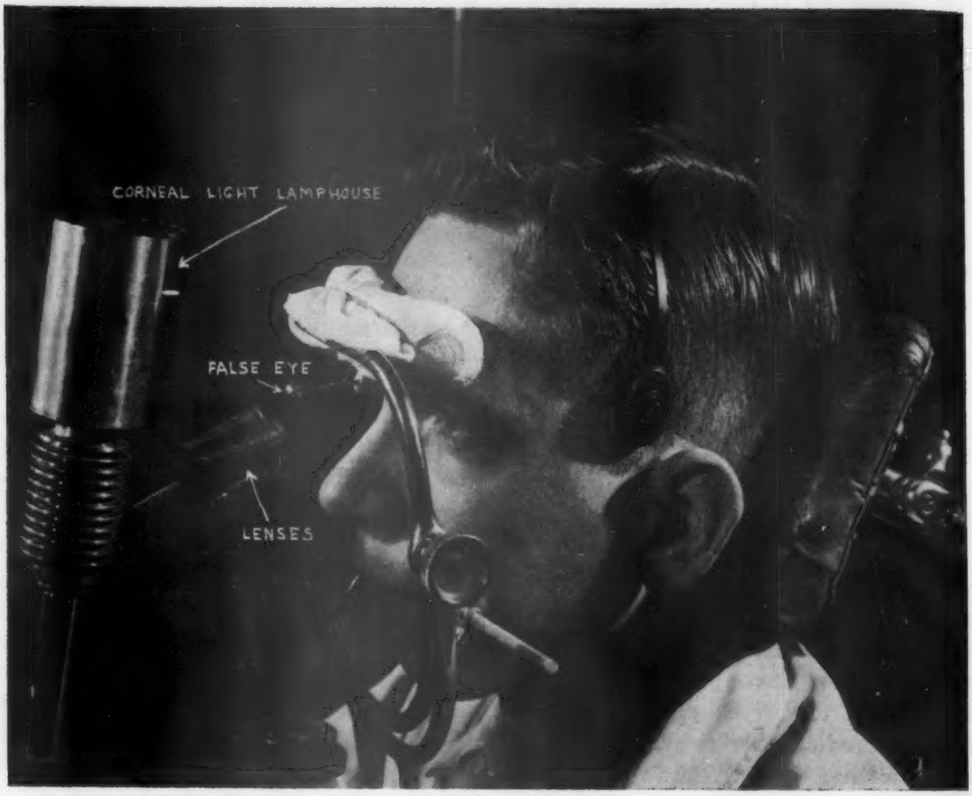

FIGURE 2. Close view of subject ready for making eye movement records.

it must be admitted that the bite stick did provide a very firm support and eliminated completely any rotating or lateral movements of the head. Furthermore, the subject did not change the bite once he had closed it on the stick at the beginning of the test run.

Several test runs of subjects looking at motion pictures were made using only the bite stick with the subject pressing his forehead against the forehead rest. It was found that the subject still tended to move his head slightly forward and backward, rotating in a vertical plane around the bite stick. This was eliminated by bringing up the headrest of the dental chair which applied pressure to either side of the head behind the ears by means of two small pads. These could be adjusted very snugly against the subject. Some subjects in the preliminary tests complained that the steel of the forehead rest was uncomfortably cold and hard, so it was covered with a thin layer of sponge rubber and a layer of gauze.

G. THE CUEING LIGHT

In the camera there was an aperture several inches to one side of the photographic aperture in which a small flashlight bulb could expose a small area of the film through a 1/8-inch aperture. The purpose of this cueing light was to make an identifying mark on the film at the moment when a particular test was be-

ginning. Thus the camera could be put into operation some time before significant eye-movement measures were to be taken. When the actual test situation occurred, the cueing light could be flashed to mark the spot on the film. Later, in the analysis of the film, an allowance could be made for a standard number of frames between the cueing light and the camera aperture so that the first eye-record scene could be accurately identified. Eye-movement records were to be taken when the subjects viewed certain scenes of a teaching film. It would be necessary to mark a definite start frame on the test film at the beginning of each scene. At the same time it was necessary to flash the cue light in the eye camera so that in the eye-record film it would be possible to identify the particular frame where the subject began looking at the test scene in the teaching film. It would not be reliable to do this manually, i.e., to have the experimenter close the switch for the cueing light when the first frame of the motion picture came on the screen, because the reaction time of the experimenter could make a considerable error in locating the start frame when the motion picture would be going by on the screen at the rate of 24 frames per second.

For this reason, a device was constructed on the motion-picture projec-

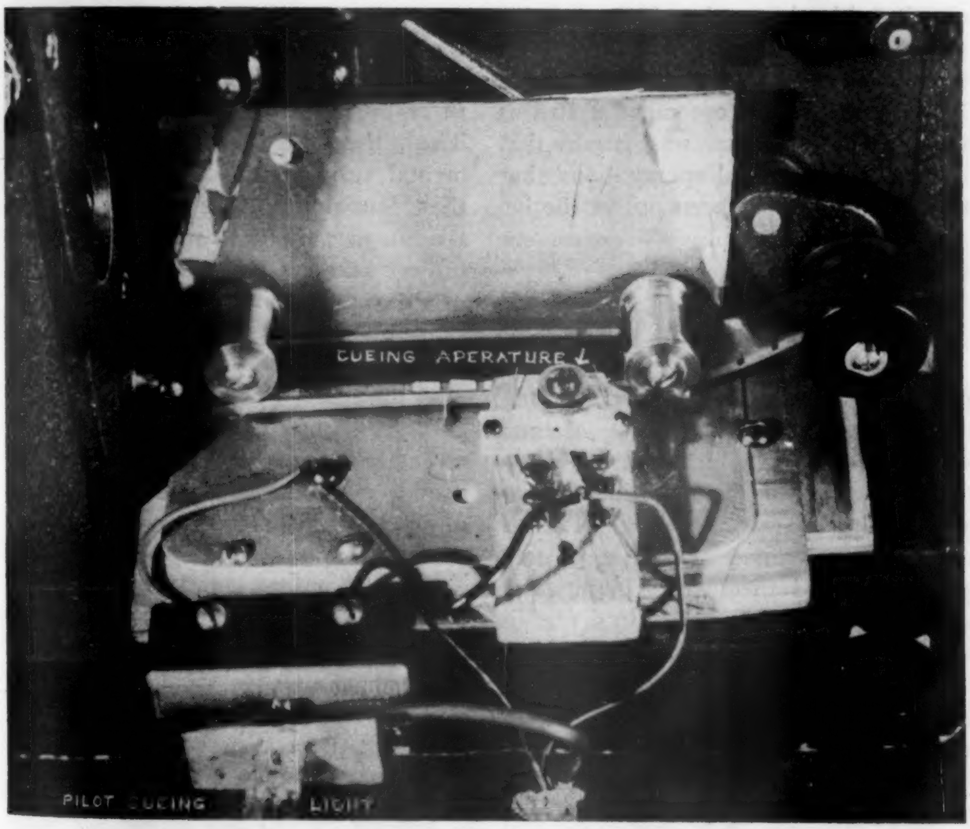

FIGURE 3. Detail of cueing device on sound motion picture projector.

tor so that the teaching film itself could activate the cueing light on the eye camera. It was decided that this cueing light should be activated and the cue mark put on the film exactly 40 frames before the start frame of each test scene. Forty frames were accurately measured on the bench and the frame for the activating device marked with a red grease pencil. At this point before each test scene three small pieces of tin foil were attached to the sprocket edge of the film by means of film cement. Three were considered essential in case one failed to activate the cueing light. These three marked frames passed through the sound projector in 1/8 of a second. A small pilot light was wired into the same circuit with the cueing light and attached to the motion-picture projector so that it would flash every time the cueing light flashed in the eye camera. In this way, the experimenter was certain that the cueing device had operated and that the flash frame had been put at the beginning of every subject's eye-camera record.

H. Registration Dots

It was necessary as usual in all eye-camera records to obtain several standard fixations at the beginning of each eye-camera record which serve as registration points for the subsequent analysis of the eye-camera record. This is customarily obtained in reading by first presenting the subject with a plain white card containing four black dots, one in each corner of the card and a short distance in from the edge. The subject is asked to look at these dots in a definite sequence, usually upper left, upper right, lower right, and lower left. These fixations appear in the photographic record of the eye movements and make it possible for the experimenter to estimate closely where in the copy the reader was fixating at the time he made any particular fixation dot.

In experimentation on motion pictures, it is even more important to have the same registration dots in order to locate the fixations in two dimensions and to determine the necessary enlargement of the eye-camera film when it is analyzed by projecting it on the screen. Therefore, a special strip of film was photographed on a title board, developed, and attached to the beginning of the test film. In this scene the registration dots appeared one by one in the usual sequence, starting at the upper left and ending at the lower left. The dots were placed some distance in from the edge of the frame so that imaginary lines connecting them would enclose three-fourths the area of the frame. Thus, the first thing that the experimental subject saw on the screen was these four dots. Before the test film was started, part of the instructions to each subject was a warning that these dots would appear and to fixate on each one as it appeared.

I. Preliminary Tests of the Camera

It was evident from the foregoing that several weeks were spent in adapting the Brandt camera to use with motion pictures. References have been made to continual tests of the operation of the camera, sometimes employing cooperating individuals and sometimes even making actual eye-camera records. However, when all the above changes had been made, fairly complete eye-camera records were made from three volunteer subjects to make a thorough test of the operation of the machine and to set up the technique and procedure of the subsequent

analysis of the eye-camera film records. Several hundred feet of 35-mm. film were exposed in the eye camera while the subjects were looking at various motion pictures. The resulting film was developed and analyzed frame by frame. Particular attention was paid to the clearness of the image and to the movement of the false eye dot which registered head movement of the subject. These preliminary tests showed that the cueing device was not dependable enough, and it was redesigned until it operated perfectly. Dr. Miles Tinker was invited to examine some of the eye records projected on the screen, and it was his opinion that the method was feasible. These tests also showed the experimenter a number of precautions to be taken, such as keeping the subject restrained in the eye-camera headrest no longer than was absolutely necessary, giving plenty of time to get accustomed to the two corneal lights before giving the test film, etc.

J. The Reliability and Validity of the Method

The method described above of measuring eye movements is fundamentally the same as that employed by Langford (4) and Buswell (2). Buswell tested the validity by having subjects look very accurately at a series of five dots placed at intervals of 1 inch in both the horizontal and vertical planes. Forty-seven subjects then plotted these known fixations. He found that the error was 1 per cent in 72 per cent of the cases, and less than 3 per cent in 91 per cent of the cases. Although Buswell did not compute the reliability statistically, it seems that the level of error is extremely low. Weymouth and others (8) have found that the central axis of the eyeball and the line of regard approximate each other within 22 minutes or less. In addition, Dodge (3) has shown that the corneal reflection method is a reliable index of the position of the eyeball.

V. THE MAKING OF EYE-MOVEMENT RECORDS IN THE LABORATORY

The typical procedure followed in the eye-camera laboratory with each subject is as follows:

Before the subject enters the room, the eye camera is loaded with sufficient film to run the complete test on that subject. The camera is opened, exposing the film mechanism, and a series of circular punch marks are put in the film to indicate the number of that particular eye-camera record. This is entered in the log book. A fresh, sterile bite stick is inserted in the eye camera headrest.

The entire teaching film is threaded into the 16-mm. sound projector. Special care is taken in threading the film through the cue-mark device to make sure that it activates the mechanism. The cue-mark device is placed 40 frames ahead of the actual start frame of each of the sequences to be tested. In order to make sure that the lower loop below the picture gate of the projector is threaded to exactly the right size, two punch marks have been placed in the leader of the film exactly 40 frames apart. The film is therefore threaded so that one of these punch marks is located exactly in the picture-projection gate and the other punch mark is centered in the cueing aperture.

When the subject enters the laboratory projection room, his name is obtained, checked off on the group list, and entered in a record book, called the log book, opposite the number of the roll of film and the number of the "take" in the camera. It is explained to the subject that he is to be shown a motion picture and at the same time the eye camera is going to photograph the movements of his eyes as he watches the picture.

After the subject is put at ease, he is placed in the dental chair which is adjusted to support his back firmly. Then the elevator mechanism raises him exactly to the point where his brow fits into the forehead rest and he is able to bite the bite stick comfortably. Then the head clamp is brought up from behind and adjusted as tightly

as possible without hurting the subject. It is explained to the subject that it is necessary to hold his head just as firmly as possible but that he must speak up if the head clamp is so tight that it hurts. The false eye is then placed over the subject's head.

At this point the lights of the room are turned out. One assistant takes the position in front of the screen and holds a small pen light exactly in the center of the screen area. The other assistant then proceeds to adjust the eye camera to the subject. He asks the subject to keep his eyes fixed on the pen light on the screen. Then he places another pen light over the ground-glass area so that its beam projects through the camera in a reverse direction from normal and casts a small spot of light near the subject's eye. Then the camera is adjusted by knobs to raise it and move it laterally until this light is centered exactly on the subject's left eye.

The corneal lights are now turned on. If their beams do not exactly hit the eyes, they are adjusted individually by loosening the rods that support them. The adjustment of the light into the left eye is only approximate but the right one is more carefully centered. The subject is then asked to look again at the pen light in the middle of the screen and finer adjustments are made on the camera. The corneal reflection is centered exactly at the crosshairs in the ground-glass aperture and then focused to as small and as bright a dot as possible by means of the focusing screw. As a final test, the subject is then asked to let his eyes roam around the screen and finally return to the pen light in the center. The action of the corneal reflection spot (later called the fixation dot) on the ground glass is noted to see that it moves only a normal distance to each side of the crosshairs.

The false eye is now adjusted so that its reflection dot appears in one corner of the ground glass. It is adjusted by manually bending the soft wire support on which it is attached to the head clamp.

The subject is now ready to view the picture. He is warned that the first thing he will see on the screen will be a series of four dots at the four corners of the screen in the following order: upper left, upper right, lower right, and lower left. One of the assistants illustrates by holding

FIGURE 4. The eye camera in the laboratory ready for operation

the pen light in these corners of the screen before the film is started. The subject is instructed to look at these four dots carefully. After that he is to view the picture in an entirely normal fashion as he would any motion picture. The subject is asked to rest his hands comfortably on each side of the table or fold them in his lap, whichever he desires. It has been previously pointed out that there is plenty of leg room under the table for the subject to move his feet any way he wishes. During the running of the film and the eye camera, one assistant remains within reach of the eye camera and the subject although keeping out of the subject's range of vision. He watches the subject to see if there is any unusual reaction to the situation which might invalidate that subject's record.

The other assistant remains beside the motion-picture projector and controls both the projector and the operation of the eye camera.

The motion-picture projector is now started. The volume control of the sound-reproduction mechanism is turned as low as possible because the film leader containing the four orientation dots consists of silent-film stock. If this were allowed to go through the sound apparatus with the sound turned on, the perforations on the sound-track side of the film would cause a distracting noise known as "motor-boating." As soon as the four orientation dots have passed, the sound volume is turned up and the film is allowed to run then normally without interruption until the last test sequence has passed.

The operator of the projector is warned of the approach of a test sequence in each case by three small bits of white adhesive tape fastened to the sprocket-hole side of the film. The appearance of these going through the projector mechanism indicates that the cue mark preceding the start frame of the test sequence by forty frames is not more than five seconds from the cue-mark gate. At the appearance of these white bits of tape the operator turns on the eye camera. This allows a safe margin so that when the silver foil activating the cue-mark mechanism goes through the cue-mark gate of the projector, the eye camera is sure to be running smoothly. At the same time the cue-mark light is activated in the eye camera, the small neon light connected in the same circuit flashes beside the projector so that the operator knows that the cue-mark light in the camera actually has been turned on. Several seconds after the test sequence has ended, the operator turns off the eye camera. The camera is restarted at the beginning of each test sequence in the teaching film.

As soon as the final sequence has passed and all the eye records are obtained, the motion-picture projector is shut off. Then the eye-camera operator quickly opens the reflex gate on the camera which allows the eye dot and the false eye dot to appear on the ground glass, and checks them for position to make sure they have not moved off the field. The subject is released from the head clamp and bite stick and allowed to sit back in comfort to view the rest of the film. As soon as the film is finished, the lights in the room are turned on.

The footage meter on the eye camera is then checked to make sure there is enough footage for the next subject. (Usually three eye-camera records can be placed on a 200-foot roll.) Then the camera is turned on for a moment in order to allow some blank film between the two adjacent eye records. The 16-mm. projection film is rewound and rethreaded ready for the next subject. The film in the camera is punched with the next number of punch holes and entered in the log book as before.

VI. ANALYSIS OF THE EYE-MOVEMENT RECORDS

When the film is unloaded in the darkroom, the punch marks in the film are located by touch so they will not be lost with any clipping of the ends of the roll. The film is developed by hand in a Stineman spiral tank system using D-72 developer and developing the image 4 to 5 minutes. This time was previously determined by developing test strips from the camera for varying lengths of time to get the utmost density without too much fog.

After development, each subject's record is identified within each roll by its punch numbers, and the name of the subject is scratched into the film with a sharp instrument. Then the film is cut to separate each subject's eye records. The individual rolls are wound up on a flange, stripped off, and held together with white Scotch Tape on which the name of the subject is written with red grease pencil. The rolls are all wound head out. That is, the orientation frame

is always on the outside of the roll. The rolls are then stored in 1,000-foot 35-mm. film cans which are sealed and temporarily placed in a film vault.

The next step is to locate on the 16-mm. print of the teaching film the exact beginning and ending of each of the test sequences. These had been roughly determined before the cueing material was affixed to the projection print, but now they are located exactly to the individual motion-picture frame. This is designated as the "start" frame. It is then necessary to locate the corresponding start frame in each eye-camera record. The first step in this process consists in determining the number of frames between the 16-mm. start frame and the cueing frame. This distance is determined for all test sequences and listed in the log book as "cue mark plus 40 frames," "cue mark plus 200." After these standard distances are entered, it is necessary to transpose this to the eye-camera film. Since the eye camera runs at 6 frames a second while the projector runs at 24 frames a second, the distance on the eye-camera record between the cue mark and the start frame is always one-quarter of the same distance on the projection print.

Thus, the projection print is used to determine the start frame and then, by counting backwards, the distance to the cue mark. This distance is divided by four and measured out on each eye-camera record starting with the cue-mark frame to locate the corresponding start frame on the eye-camera record.

The 16-mm. print is also used to determine the length of each test sequence measured in frames. This is again divided by four to determine how many frames of the eye-camera record after the start frame should be analyzed.

To facilitate the marking of the start frames on each eye-camera record, the different distances are laid out on a scale on a work bench. By using this, the start frames for each of the sequences in each eye record can be measured and marked quickly and accurately. The start frames are indicated on the film by outlining the frame and marking it with an X with a red grease pencil. Furthermore, the two frames preceding each of the start frames are marked with a red arrow pointing toward the tail of the film and indicating the number of the sequence whose start frame follows immediately after the arrow.

Two measures are read from these eye records: the amount of saccadic movement and the pause duration. On Dr. Tinker's advice, it was decided to call the amount of saccadic movement "interfixation movement." The term "sweep" cannot be applied because this refers to movement of the eye in reading in returning from the end of one line to the beginning of the next. The term "span" cannot be used here because this has been used specifically to refer to the number of words in reading comprehended in one fixation point. It was thought best, therefore, to use the term "interfixation movement" as applying to the straight-line distance between two fixations in viewing pictures of two dimensions.

It was decided to use the unit 1/24 of a second as the basic unit in measuring pause duration, simply because an empirical study of the eye records in a pilot experiment had indicated that there would be no pause durations shorter than this.

For convenience, two graph-paper data books are used in recording the interfixation range and the pause duration for each subject. Half of a double page

FIGURE 5. The laboratory analysis of eye-movement records

is assigned to each subject. Successive rows are labeled according to sequences. Vertical columns are numbered from one upwards to indicate frames out of the eye-camera film record.

The method used in reading the two measures of eye movement is to thread the eye-camera film into a 300-W. air-cooled filmstrip projector and project the film frame by frame on a fairly large screen. The projector is fitted with a single frame attachment so that only one frame of the film record is analyzed at a time, without any possibility of confusion. Because the eye camera moves the film horizontally through the eye-camera aperture, the eye-camera records have to be projected in a filmstrip projector which will similarly move the film from left to right through the filmstrip aperture. The distance from the projector to the screen, technically called the throw, is unimportant because there is no interest in the absolute movement of the eye which can only be measured in spherical angles; to be measured is the relative movement measured linearly on the plane of the screen without reference to the direction of movement. The relative eye-movement measures provide the data for the measurements of association between eye movement and other experimental factors.

It might be supposed that greater accuracy in measuring the interfixation movement might be obtained by moving

the projector farther away from the screen since this would enlarge all the details on the screen. However, such great magnification is not useful because the factor limiting the accuracy of measurement is the sharpness of the image of the fixation dots on the film.

The screen consists of a piece of matte-white screen fabric fastened over a sheet of cork mounted on a solid frame. The cork is necessary to allow several pins to be stuck into the projection surface at one time. It is necessary to darken the room only partly because the powerful projector shining through the almost clear eye-record film produces a brilliant image on the screen.

Two assistants are necessary to operate this equipment. One assistant remains seated at one end of the room beside the filmstrip projector. Her part is to thread the individual eye-camera records into the filmstrip projector, advance the film to the start frame, and then advance it frame by frame as the data are collected. As each frame is projected, she tilts and moves the projector from side to side when necessary to superimpose the false eye registration dot over its previous position, thereby automatically correcting for the subject's head movement. After the record is run through, she rewinds it so that it is placed head out in the storage cans. It is also her responsibility to take charge of the data record book, entering the data as they are called out by the other assistant. She also assists the other worker in verifying the exact location of the eye dots on the screen.

The second assistant is seated at the other end of the room in front of the screen. When the start frame appears on the screen, the assistant at the screen, with the help of the assistant at the projector, locates the exact center of the false eye registration dot and puts a pin in the screen at that point. Then she locates the center of the fixation dot in that frame and puts a pin in that. The clerk at the projector then advances the eye record one frame. The first step in reading the second frame, as in all subsequent frames, is to determine if the false eye dot is still centered on the pin marking it. If it is not, the projectionist turns and tilts the projector until the false eye dot is superimposed on the pin again. The location of the fixation dot in the second frame is made after the false eye dot has been realigned or immediately if this realignment is not necessary as happens in most cases. A pin is placed in the center of the fixation dot in the second frame. Then the distance between the fixation-dot pin established in Frame 1 and the fixation-dot pin established in Frame 2 is read aloud in millimeters. The assistant at the projector records this as the first inter-fixation range measurement for that particular scene for that subject. Then both assistants determine whether there are any other fixation points in that frame. If there are not, the pause duration is also entered as 4/24 of a second.

Occasionally more than one fixation dot appears in one frame, indicating that there was more than one fixation in the 4/24 of a second that that frame remained motionless in the eye-camera gate. It is easy to determine by the relative density of the two, three, or four dots whether the pause duration should be listed as 3/24, 2/24, or 1/24.

The collection of all our data on eye movement follows this procedure except for a few variations. One variation occurs when the fixation dot of the subject goes so far off to one side that it runs off the screen. This probably indicates that when the record was made, the sub-

ject was not even looking at the motion picture, but glanced away from the projection screen. In this case, the operators go back to the previous frame of the eye record and deliberately re-establish the false eye dot a sufficient distance to one side or another so as to bring the eye dot back on the screen where it can be located. Then the measuring and the collecting of data proceed in the normal fashion.

Another interruption of the normal procedure is the occurrence of blinks by the subject. The evidence of this is merely the absence of any fixation dot whatsoever. This condition lasts approximately anywhere from 1 to 5 frames. The false eye dot is, of course, present in every frame, indicating that the absence of the fixation dot was not due to failure of the corneal light. Furthermore, the frame just before a blink always shows small light streaks radiating from the fixation dot. There are usually two light streaks extending in opposite directions from the fixation dot and somewhat resembling a blur caused in photographing a moving object. These peculiar "blink warnings" make it possible to differentiate a blink from the situation where the subject might look so far away to one side from the motion picture that the fixation dot would not be photographed at all.

In general, it is found that the false eye dot remains in much the same position. When it does move, however, it is characteristic of it to move down gradually from frame to frame and then suddenly to jump back up into its original position. The rigid control of the head movement of the subjects while the camera records are being made prevents any erratic head movements.

After all the eye records are measured, their accuracy is checked by a team of two other individuals who remeasure sample eye records chosen at random among all the subjects. One check showed that the original records were extremely accurate and dependable. The averages of the eye-movement measures determined for each student for each scene differed by only one per cent between the original analyses and the checking analyses.

At the conclusion of the data collecting, all the eye-camera film is stored again in fireproof cans, taped up and returned to the film vaults.

VII. SUMMARY

The Brandt camera (1) was modified to permit photographing eye movements in two dimensions by the corneal-reflection method while the subject is viewing a motion picture. The Brandt camera moves the film intermittently as in a motion-picture camera, but at the relatively slow rate of two frames per second. In the modified camera, this rate is increased to six frames per second. Synchronization of the eye-camera film with the motion picture being viewed is achieved by a cueing light. To permit analysis, the resulting film record is projected (by means of a filmstrip projector) on a screen, where successive fixation points can be marked and interfixation movement can be measured linearly. Corrections for head movements are made at the same time by continually recentering the projected film image of a false eye worn by the subject.

This method of photographing eye movements of subjects viewing educational motion pictures is feasible and is

recommended for use in further investigations in this field. The method makes possible the study of individual scenes and sequences of teaching films. Such study is needed to assure that the films have been planned and executed in a manner to achieve maximum teaching benefits at minimum production costs.

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